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AN ECONOMIC MODEL FOR SEABORNE OIL TRADE

by

Kian-Wah, Hong

March, 1996

Thesis Advisor: Dan Boger
Co-Advisor: Gregory Hildebrandt

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AN ECONOMIC MODEL FOR SEABORNE OIL TRADE

Kian-Wah, Hong
Major, Republic of Singapore Navy
B.Eng., University of London, 1988

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of the requirements for the degree of

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Author: ______________________
Kain-Wah Hong

Approved by: ______________________
Dan Boger, Thesis Advisor

____
Gregory Hildebrandt, Co-Advisor

____
Frank Petho, Chairman
Department of Operations Research

ABSTRACT

This thesis aims to provide some insights as to how oil prices and oil flows might vary with the carrying capacity of the tanker fleet as affected by political events. It provides an econometric analysis of tanker freight rates in the modern era and proposes a mathematical (quadratic) programming economic model that links the crude oil market to the supply elasticity of the world oil tanker fleet based on a competitive economy. The economic model can be considered as a version of the Walras-Cassel general-equilibrium system which possesses an economically meaningful equilibrium solution in terms of oil prices, freight rates and the pattern of oil distribution. The implementation of the model is completed using the General Algebraic Modeling System (GAMS). The study concludes with a scenario study showing how the model could be used to examine the importance of South East Asia's sealanes in world seaborne oil trade. The model shows the economic vulnerability of oil importing nations, especially Japan, the United States, and Western Europe, to a possible closure of South East Asian sealanes.

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EXECUTIVE SUMMARY

In view of the continuous discoveries of new oil fields as well as upward revisions of the world's proven reserves, it seems clear that oil will continue to be the major energy source for the foreseeable future. The development of the giant oil-tankers has resulted in a highly inflexible system dependent on narrowly specified sea lanes between relatively few given ports. The vulnerability of seaborne oil is amplified by the length of shipping routes and more effective weapon systems. This thesis aims to provide some insights as to how oil prices and oil flows might vary with the carrying capacity of the tanker fleet as affected by political events. It provides an econometric analysis of tanker freight rates in the modern era and proposes a mathematical (quadratic) programming economic model that links the crude oil market to the supply elasticity of the world oil tanker fleet based on a competitive economy.

The results of the traditional static economic analysis suggests that the Suez Canal has lost its profound influence on freight rates since its reopening in 1975. This is due to the development of supertankers such as the VLCCs and ULCCs, resulting in a highly competitive Cape of Good Hope route. It is also shown that freight rates are closely linked to tanker activities such as lay-up, delivery and utilization as one would expect.

The second part of the study examines the issue using a dynamic approach based on the classic economic equilibrium theory and nonlinear programming. The dynamic model of seaborne oil trade provides analysts with a way to factor in the price-sensitive demand and supply of oil and tankers which would not be possible with the traditional static statistical approach. The model was implemented using the General Algebraic Modeling System (GAMS) and used to examine the importance of South East Asia's sealanes in the global seaborne oil trade. The results suggest that major oil importing nations such as Japan, the United States and Western European nations, as well as the biggest oil supplier of Japan, the Middle East, should not underrate the importance of these sealanes. In situations where the shipping supply is highly inelastic, which is often the case in the short-run, the closure of South East Asia's sealanes would place an enormous pressure on the world's fleets and cause tanker freight rates to soar. These sealanes are more than virtual lifelines to South East Asian nations and Japan; many other nations, both oil importers and oil exporters, would also find themselves subsidizing the high freight rates should the incident arise. The development of supertankers has relieved the dependence of the West on the Suez Canal but it has also created a highly inflexible and vulnerable shipping system. For those nations whose economies depend on oceanborne supply lanes, it is imperative to secure and protect South East Asia's sealanes.

I. INTRODUCTION

Henri Berenger, French diplomat 1921, said "He who owns the oil will own the world, for he will rule the sea by means of the heavy oils, the air by means of the ultra-refined oils, and the land by means of gasoline and the illuminating oils." (Goralski and Freeburg[1987]). In view of the continuous discoveries of new oil fields as well as upward revisions of the world's proven reserves, it seems clear that oil will continue to be the major energy source for the foreseeable future. The aim of this study is to provide some insights to how oil prices and oil flows might vary with the variation in the carrying capacity of the tanker fleet as affected by political events.

A. BACKGROUND

Most of the major oil-consuming nations depend on imported supplies, which necessitates large-scale seaborne movements of oil. To maintain a steady, increasing flow of oil at lowest possible transportation costs, larger ships and ports have been developed in Free World nations. One modern mammoth tanker carries more oil than an entire convoy during the last world war. The development of the giant oil-tankers has also resulted in a highly inflexible system dependent on narrowly specified sea lanes between relatively few given ports, making seaborne oil considerably more vulnerable to shipping warfare today than during World War II. Simply the announcement that a particular route has been mined, might be enough to disrupt shipping patterns or at least cause costly delays during sweeping operations. The vulnerability is further amplified by the effectiveness of modern weapon efficiency. Today, one well-aimed torpedo at one target will have a greater effect than anything achieved in the 1940s. More simply stated: the mere availability of a weapon system, as opposed to its actual use, could be sufficient to disrupt shipping patterns.

Any disruption to the shipping patterns can be represented by a change in the carrying capacity of the tanker fleet. For examples, the Suez crisis in 1956 caused oil tankers trading to Europe to divert round the Cape; the Yom Kippur War in 1973 and the OPEC production cut back resulted in the collapse of the tanker market. Both events triggered a sudden change in

tanker demand in tonnages or tonnage-miles terms. This study examines the relationships among oil prices, oil distribution patterns, freight rates and the carrying capacity of the tanker fleet as affected by potential political events.

B. OUTLINE

Chapter II provides an econometric analysis on the tanker freight rates in the modern era --- the period which marks the end of an unprecedented growth of seaborne oil trade from 1974 to the late 1980's. The effects of freight rates cannot be underrated in the seaborne oil trade, especially so when the transportation cost forms a significant portion of the overall import cost. For any quantity of seaborne oil trade between two countries to occur, the price appreciation (difference in the market price and supply price) must not fall short of the unit shipping cost (a function of tanker freight rate and distance) from the exporting country to the importing.

Chapter III presents a mathematical (quadratic programming) economic model that links the crude oil market to the supply-elasticity of the world oil tanker fleet based on a competitive economy. The model would allow one to examine the possible effects of tanker supply elasticity on the seaborne oil trade in both short-run (a period too short for significant changes to occur in overall shipping capacity through newbuilding, i.e., the supply would be inelastic) and long-run (relatively more elastic supply) scenarios. It can also be viewed as a version of the Walras-Cassel general-equilibrium system which will be shown in Chapter III, possesses an economically meaningful equilibrium solution in terms of oil prices, the pattern of oil distribution, freight rates and tanker supply. The implementation of the model is completed using the General Algebraic Modeling System (GAMS).

Chapter IV discusses a scenario study using the model. The scenario study examines the importance of sealanes in South East Asia to the world seaborne oil trade. Finally, conclusions and possible ideas for future research are presented in Chapter V.

II. ECONOMIC CHARACTERISTICS OF MODERN FREIGHT RATES

Stopford[1988] characterizes the period from 1974 to 1986 as a period of shipping depression with very poor financial returns. In the tanker market, the 1973 Yom Kippur War ushered in a decade of depression relieved only by a brief market improvement in 1979. By 1985, the tonnage of crude oil shipping by sea had fallen from 1973's high of 1,640 million metric tons to 1,159 million metric tons. Despite the decline in demand, the world tanker fleet continued its unprecedented growth till the early 1980s, widening the supply/demand gap even further. This chapter examines the behavior of freight rates in the modern era, starting in 1974 as defined by Stopford [1988], by means of econometric analysis. Due to the difficulty in obtaining all relevent data, this study would only examining the period till 1987. I have assumed a linear relationship (to be validated in the study) between freight rates and the independent variables.

Section A presents the proposed statistical model and definitions of variables used in the model. Results of various statistical tests and final analyses are shown in Section B and Section C, respectively.

A. STATISTICAL MODEL

The analysis depicts the yearly averaged freight rate (Y, in worldscale --- a freight index designed to express tanker rates, irrespective of vessel size and route, in terms of the costing of a standard vessel) as a function of seven independent variables (X's):

X_1 = years (1974..1987)

X_2 = tanker potential productivity

≡tanker demand in ton-miles (Fearnleys, 1988) / active tanker fleet in dwt (OCED, 1988)

X_3 = average haul in miles

≡tanker demand in ton-miles (Fearnleys, 1988) / tanker demand in tons (Jacobs, 1988)

X_4 = active tanker fleet in tons (Jacobs, 1988)

X_5 = percentage of tanker fleet laid up

≡tanker laid up in tons (Jacobs, 1988) / total tanker fleet (Fearnleys, 1988)

X_6 = oil prices in 1993 dollars (US Department of Energy, 1995)

X_7 = percentage of oil shipped via the Suez Canal (closed in 1974, reopened in Jun'75)

≡tanker traffic via Suez in tons (OECD, 1988) / X_4

.B. STATISTICAL TESTS AND INTERPRETATION

1. Regression Equations

The regression equation giving the best fit is <standard error> [p-value]{variance inflation factor, Equation (2.4)}:

$$Y = 28578 - 14.33\,X_1 + 48.84\,X_2 - 0.084\,X_3 + 0.585\,X_4 - 2.985\,X_5 - 1.122\,X_6 + 6.691\,X_7$$

<6.956>	<6542>	<3.2920>	<17.050>	<0.0143>	<0.1520>	<0.8495>	<0.4329>	<5.0170>
[0.000]	[0.005]	[0.005]	[0.029]	[0.001]	[0.008]	[0.013]	[0.041]	[0.231]

R^2 (adjusted) = 0.939 (2.1)

Excluding X_7, the regression equation giving the best fit is:

$$Y = 21807 - 10.90\,X_1 + 48.35\,X_2 - 0.082\,X_3 + 0.497\,X_4 - 2.113\,X_5 - 0.939\,X_6$$

<7.333>	<4349>	<2.1660>	<17.960>	<0.0149>	<0.1444>	<0.5722>	<0.4328>
[0.000]	[0.000]	[0.000]	[0.031]	[0.000]	[0.011]	[0.008]	[0.067]

R^2 (adjusted) = 0.932 (2.2)

Excluding X_6, the regression equation giving the best fit is:

$$Y = 16982 - 8.531\,X_1 + 75.50\,X_2 - 0.078\,X_3 + 0.430\,X_4 - 1.786\,X_5 + 2.564\,X_7$$

<9.377)	<4349>	<2.1660>	<17.960>	<0.0149>	<0.1444>	<0.5722>	<0.4328>
[0.001]	[0.033]	[0.034]	[0.004]	[0.005]	[0.056]	[0.105]	[0.701]

R^2 (adjusted) = 0.889 (2.3)

Excluding X_6 and X_7, the regression equation giving the best fit is:

$$Y = 14903 - 7.472\,X_1 + 73.42\,X_2 - 0.077\,X_3 + 0.404\,X_4 - 1.498\,X_5$$

<8.871>	<3587>	<1.7930>	<16.650>	<0.0179>	<0.1668>	<0.6015>
[0.000]	[0.003]	[0.003]	[0.002]	[0.003]	[0.042]	[0.037]
		{9.3}	{16.9}	{37.0}	{7.7}	{1.7}

R^2 (adjusted) = 0.901 (2.4)

2. Significance Tests

At a critical level of 5% (two tails), the results suggest the following relationships (analysis in Section C) between the indpendent variables and the freight rate:

Year (X_1) versus Freight Rate	~	Negative Relationship
Productivity (X_2) versus Freight Rate	~	Positive Relationship
Average Haul (X_3) versus Freight Rate	~	Negative Relationship
Active Fleet (X_4) versus Freight Rate	~	Positive Relationship
Laid Up (X_5) versus Freight Rate	~	Negative Relationship
Oil Price (X_6) versus Freight Rate	~	No Significant Relationship (negative at a critical level of 7%)
Suez Canal Oil Traffic (X_7) versus Freight Rate	~	No Significant Relationship

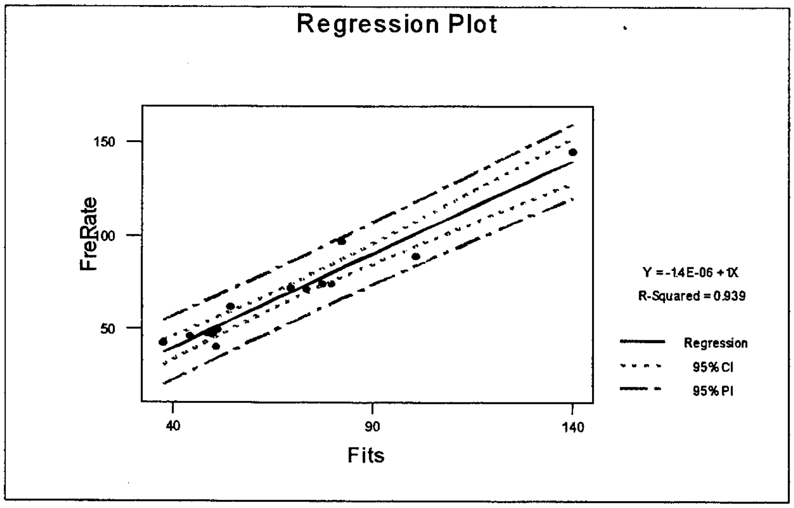

Figure 2.1

Figure 2.1 gives the regression plot of Equation (2.4). The only outlier (which corresponds to the 1974 data) does not seem to have any strong influences on the regression (fortunately) as it very much follows the trend. The results show that X_6 and X_7 have no significant effect on the freight rates. It is not surprising to find some instability in the initial equation (Equation (2.1), as well as Equation (2.3)) in view of the high intercorrelation that exists between X_7 and the other independent variables. This is shown in Table 2.1.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	Y
X_1	1.000	*	*	*	*	*	*	-0.725
X_2	-0.848	1.000	*	*	*	*	*	0.819
X_3	-0.938	0.874	1.000	*	*	*	*	0.647
X_4	-0.569	0.307	0.682	1.000	*	*	*	0.258
X_5	0.321	-0.421	-0.411	-0.409	1.000	*	*	-0.605
X_6	-0.098	-0.350	0.027	0.552	-0.135	1.000	*	-0.205
X_7	0.940	-0.852	-0.940	-0.657	0.572	-0.101	1.000	-0.779

Table 2.1 Correlations (Pearson)

The results also show the effect of precision reduction in model due to the inclusion of an irrelevant variable. Note that, with X_6 excluded, the standard errors associated with the coefficients of the regression equation with X_7 (Equation (2.3)) are significantly higher when compared to that of the equation with X_7 omitted (Equation(2.4)). This is expected because X_7 is highly correlated with other variables, and incorrectly including it in the regression would inevitably inflate the standard errors of the others. The effect of including X_6 in the regression is not as apparent since it is not highly correlated with other variables.

3. Multicollinearity Checks

To check whether the high R^2 (=0.9, adjusted) in the final regression could have been inflated by the high intercorrelations between X_1, X_2 and X_3, I looked for the symptoms of multicollinearity listed by Greene[1993]. Removing more than one observation to test the stability of the model might not be feasible here as there are fewer than 15 observations available for this study. With just the 1987 data omitted, the parameter estimates were found to be stable and no wide swings in their values were noted. The coefficients have low standard errors, high significance levels exceeding 95%, sensible signs (which will be elaborated in a subsequent section) and magnitude. Moreover, the square root of the maximum variance inflation factor (Equation(2.4)) is well below 20 suggesting that the collinearity, if any, is not significant. Berk [1977] shows that the condition number must be at least as large as the square root of the maximum variance inflation factor, so this latter statistic could be used in place of the condition

number without much loss of information.

4. Normality Test

Visual inspection does not reveal any significant abnormality in the residuals and the result of an Anderson-Darling normality test confirms (see Figure 2.2) that the residuals are indeed very random or normally distributed at a critical level of 95%.

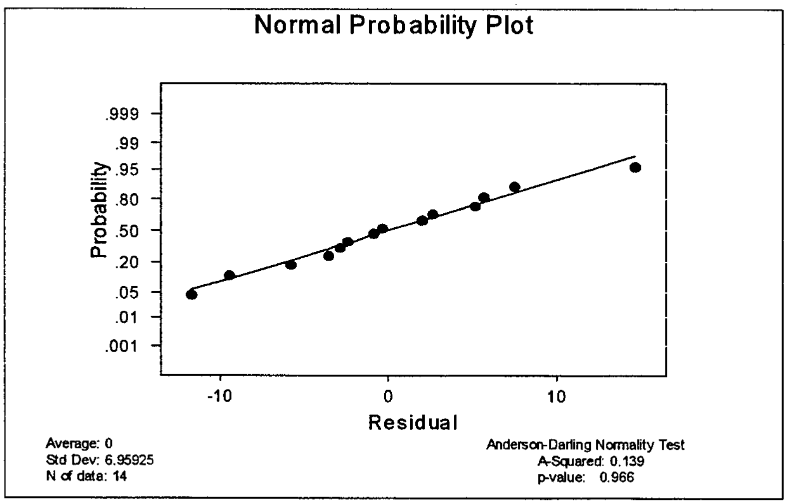

Figure 2.2

5. Heteroscedasticity Tests

Figure 2.3 displays the scatter plots of residuals versus the fits and the five independent variables. Again, no clear patterns are observed (some are ambiguous). To check for possible heteroscedasticity, Breusch-Pagan/Godfrey [1979] tests were conducted (there are insufficient data to conduct the White test [1980] nor the Goldfeld-Quandt test [1965]). The summarized outcomes are as follows:

- with all independent variables included: LM (or ExpSS/2) = 4.85, reject the null hypothesis and the model is heteroscedastic.
- with X_4 removed from "Z": LM (or ExpSS/2) = 0.30, do not reject the null hypothesis that the model is homoscedastic.

The results suggest that X_4 is probably the key source of heteroscedasticity associated with the model. Closer examination of the scatter plot of residuals versus X_4 (Figure 2.3d) reveals a decreasing trend in the variance with the exception of two outliers which correspond to X_4 =

290. The two relatively large outliers have also denied any possible use of a stabilizing

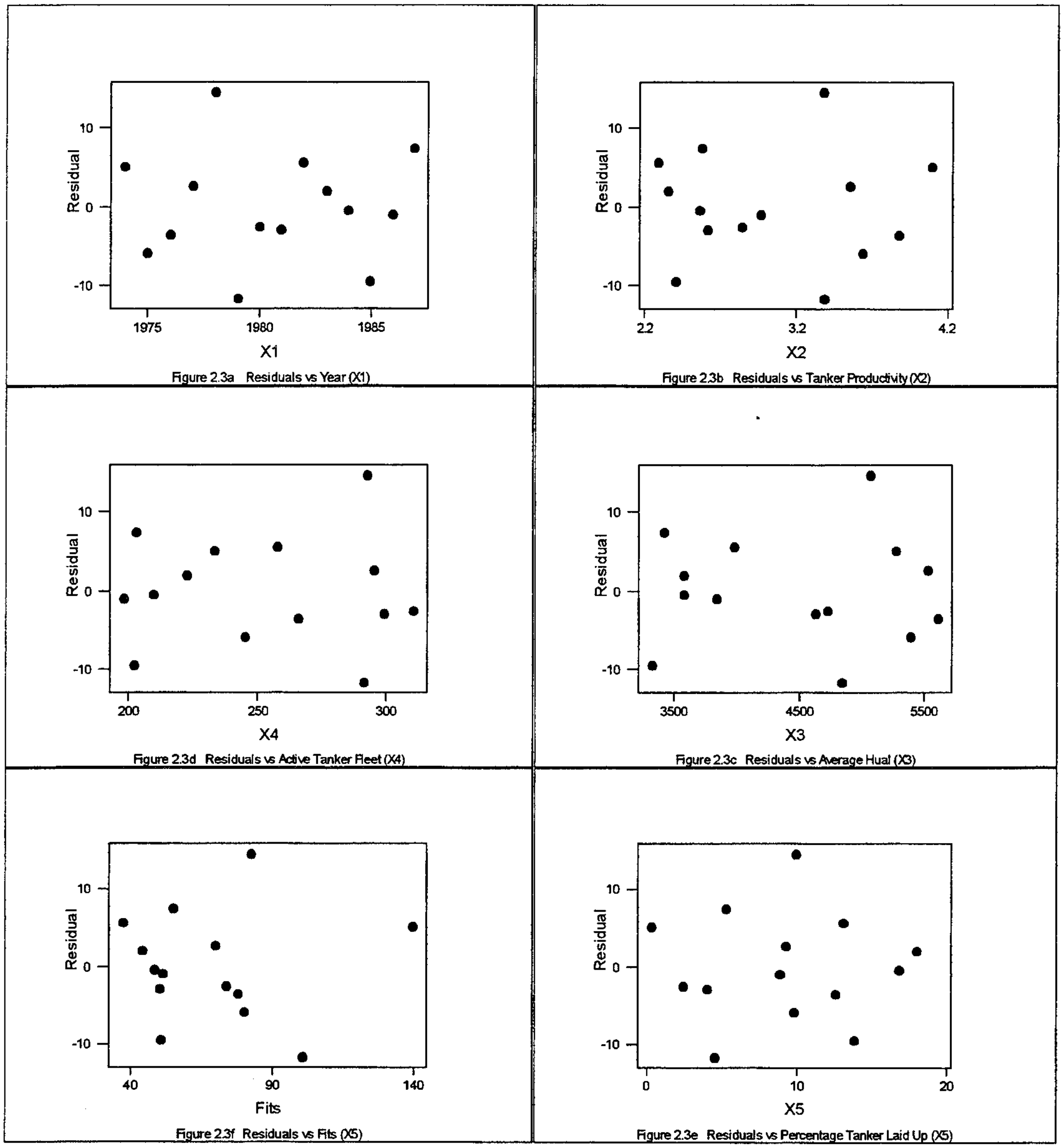

Figure 2.3

transformation to "normalize" the effect of X_4 (I tried a few typical transformations on X_4, but these failed). Therefore, the estimated variance of the ordinary least squares (OLS) estimator would be biased. White [1980] has shown that it is still possible to obtain an appropriate estimator for the variance of the least square estimator, even if the heteroscedasticity is related to the

independent variables. Using the White estimator for the variance matrix of the least squares estimators produces the results below shown in Table 2.2.

	Constant	X_1	X_2	X_3	X_4	X_5
Coefficient	14903	-7.472	73.42	-0.077	0.404	-1.498
OLS Std Error	3587	1.7930	16.650	0.0179	0.1668	0.6015
White Std Error	1723	0.8624	16.867	0.0164	0.1856	0.4379

Table 2.2 Estimated variances using OLS and White estimator.

Except for X_2 and X_4, the corrected standard errors are smaller than the conventional computed values, and all slope coefficients remain statistically significant at the critical level of 95% after the correction. Therefore, the detected heteroscedasticity does not have negative implications in this case and the initial assessments using OLS, Equation(2.4), are validated with smaller standard errors.

6. Autocorrelation Tests

To check for possible autocorrelation, an AR(1) test was conducted and the Durbin-Waston statistic was found to be 2.24. At a critical level of 95%, the statistic falls in the inconclusive region between 0.505 and 2.296. Therefore, nothing could be said about the hypothesis testing. An alternative test suggested by Ljung and Box [1979] allows also the tests of autocorrelation at different lags. Applying the test for lag 1, 2 and 3, see results in Table 2.3. The Ljung and Box statistics suggest that there is no significant autocorrelation in the data.

Lag	Ljung and Box Q Statistic	p-value
1	0.59	0.44
2	3.08	0.21
3	5.30	0.15

Table 2.3 Ljung and Box Q Statistic

C. ANALYSIS

These results are consistent with what we expected on purely theoretical considerations. Since the 1956 crisis, the dependence of the West on the Suez Canal has declined significantly. By employing VLCCs, the Cape of Good Hope route was highly competitive with the Suez Canal and the closing of the Suez Canal in 1967 did not disrupt oil supplies as severely as in 1956. On the assumption that the canal might be closed permanently or that its use might be tied to political considerations and objectives, many shipowners have ignored the canal as a potential route. By 1987, the percentage of oil shipped via the Suez Canal had decreased from the 1960s high of 19% to about 6% and so had the dependence of freight rates on the Suez Canal (X_7). During the period from 1974 to 1987, there was no shortage of tanker supply and to the contrary, a significant oversupply was noted during the period. It is therefore not surprising that to find that oil prices (X_6) and freight rates are very weakly negatively correlated due to the high price-elasticity of tanker supply during the period and the "willingness" of shipowners to subsidize a portion of any increase in oil prices to sustain the overall shipping demand.

The "years" (X_1) reflect the technological developments such as the increased efficiency in port services, higher ship speeds and more rapid repairs. Such developments have the effect of turning-around tankers faster and generating more shipping capacity in terms of ton-miles per dwt. The increased efficiency in shipping will lower the shipping cost, thus lowering the freight rate. The productivity or utilization rates (X_2) are correctly positively related with freight rates. The relationship indicates that high utilization rates or high levels of competition often lead to high freight rates and vice versa as expected. The average haul (X_3) or the average distance in which a unit of oil is shipped is found to be negatively related with the freight rates. This shows the effect of the employment of larger tankers such as the VLCCs and ULCCs over the years. Size reflects the economies of scale and also the increase in shipping distances as larger tankers cannot take advantage of many short routes which make use of narrow straits and canals. A positive relationship is also noted between the active tanker fleet (X_4) and freight rates which indicates that when new tankers due for delivery are being speeded up and maintenance of tankers delayed, the prospect of having high freight rates is good. Similarly, in situations where shipowners choose to wait out periods of uncertainty by stretching out necessary repairs, the

freight rates are expected to remain low. The empirical evidence also suggests that more tankers would be laid up or scrapped (X_5) during the low freight-rate periods and thus, the negative relationships as anticipated.

The study has illustrated the difficulties in dealing with real data. Such data often contains high intercorrelations and some forms of nonlinearity, making the variable selection process difficult. The results have provided also valuable insights to the understanding of the market forces that determine annual averaged tanker freight rates and quantitative relationships that can be used to shape management policy in the areas of tankship operations. However, one must recognize that such a stastistical model is static. In this particular case, the period examined represents an era of tanker oversupply and low freight rates and the results will not be good for predicting or estimating responses when the supply of tankers is very close to the demand, i.e., when the tanker productivity is very high. Stopford [1988] provides an excellent discussion on how a small increase in demand can treble the freight rate when the supply of tankers is low. The next chapter proposes a mathematical model based on the classic economic equilibrium theory that would allow one to examine the elasticity effects of the shipping supply on freight rates, oil prices and its distribution pattern.

III. SEABORNE OIL TRADE ECONOMIC MODEL

This chapter shows how the classic economic equilibrium theory can be used to model the seaborne oil trade. It begins with a short review on the classic Walras-Cassel economic equilibrium system and shows how such system can be transformed to a generalized transportation problem. The incorporation of a set of price-sensitive supply and demand functions to this transportation problem results in a simple seaborne oil trade model that would allow one to investigate the effects of tanker (transport) supply elasticity on the oil trade. The model complements the static model presented in the previous chapter, providing a means for analysts to examine the dynamic supply and demand aspects of seaborne oil trade.

A. CLASSIC ECONOMIC EQUILIBRIUM THEORY

The neoclassical economic equilibrium system was originally expounded by Walras (Dorfman, Samuelson and Solow [1958]). Consider an economy with n commodities and m resources. Let s_i be the amount of the ith resource or factor supplied and let b_j be the amount of the jth commodity produced. Technical production possibilities are characterized by mn fixed numbers a_{ij}, with each input coefficient representing the physical amount of the ith resource used up in the manufacture of a unit of the jth commodity. To obtain the supply for each resource or factor from its demand, we get m equations:

$$\begin{aligned} a_{11}b_1 + a_{12}b_2 + \ldots\ldots\ldots\ldots + a_{1n}b_n &= s_1 \\ a_{21}b_1 + a_{22}b_2 + \ldots\ldots\ldots\ldots + a_{2n}b_n &= s_2 \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ a_{m1}b_1 + a_{m2}b_2 + \ldots\ldots\ldots\ldots + a_{mn}b_n &= s_m \end{aligned} \tag{3.1}$$

Let $p_j = f_j(b_1, \ldots, b_n)$ (or the jth demand function) be the price of the jth commodity and let $q_i = f_i(s_1, \ldots, s_m)$ (or the ith supply function) be the price or rent of the service of the ith resource or factor. All that is needed now to round out the classic Walras-Cassel system is to equate the price of each commodity to its unit costs, we get another n equations:

$$
\begin{aligned}
a_{11}q_1 + a_{21}q_2 + \dots\dots\dots\dots\dots\dots & + a_{m1}q_m = p_1 \\
a_{12}q_1 + a_{22}q_2 + \dots\dots\dots\dots\dots\dots & + a_{m2}q_m = p_2 \\
\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots & \\
a_{1n}q_1 + a_{2n}q_2 + \dots\dots\dots\dots\dots\dots & + a_{mn}q_m = p_n \qquad (3.2)
\end{aligned}
$$

Each household's demands and supplies are subject to a budget constraint which says that outlays on goods equals income from resource services. Since this is true for each household separately, it is true for the aggregate. Hence they must satisfy an identity or the Walras' law, $\Sigma_j p_j b_j \equiv \Sigma_i q_i s_i$ (value of output $\equiv$ total income).

Dorfman, Samuelson and Solow [1958] show that if m > n, the Walras-Cassel system as written in Equations (3.1) and (3.2), will, in general, have no equilibrium solution. Suppose there is only one commodity, a unit of which is produced by 1 unit of labor and 1 unit of land. If the avaiable supplies are 2 labor and 1 land, how can Equations (3.1) be satisfied and all of both resources used? Taking Equations (3.1) literally, they require that the demand for each resource should just equal the given constant supply. In effect, the solution of the equations would be something like the intersection of a derived demand curve with a perfectly inelastic supply curve. Although it is not possible for a set of outputs to use up more of a resource than is available, it is possible that some amount of a particular resource could be left unused or "free". Zeuthen and Neisser pointed out that the market determines which goods shall be free and which scarce (Dorfman, Samuelson and Solow [1958]). Equations (3.1) have to be modified to read

$$
\begin{aligned}
a_{11}b_1 + a_{12}b_2 + \dots\dots\dots\dots\dots\dots & + a_{1n}b_n \le s_1 \\
a_{21}b_1 + a_{22}b_2 + \dots\dots\dots\dots\dots\dots & + a_{2n}b_n \le s_2 \\
\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots & \\
a_{m1}b_1 + a_{m2}b_2 + \dots\dots\dots\dots\dots\dots & + a_{mn}b_n \le s_m \qquad (3.1a)
\end{aligned}
$$

with further condition that if the strict inequality holds in any line of (3.1a), i.e., if any resource -- say the kth -- is less than fully employed, then its price q_k must be zero.

As for the price-equals-unit-cost equations (3.2), there is nothing wrong for the unit cost to exceed price. It is exactly what one would expect of commodities not being produced -- that price should not cover unit costs at any positive output. Replace the n equations (3.2) by n inequalities:

$$a_{11}q_1 + a_{21}q_2 + \dots\dots\dots\dots + a_{m1}q_m \geq p_1$$

$$a_{12}q_1 + a_{22}q_2 + \dots\dots\dots\dots + a_{m2}q_m \geq p_2$$

$$\dots\dots\dots\dots\dots\dots\dots\dots$$

$$a_{1n}q_1 + a_{2n}q_2 + \dots\dots\dots\dots + a_{mn}q_m \geq p_n \tag{3.2a}$$

with the provision that if inequality holds in one or more lines of (3.2a), the corresponding output b must be zero.

The first rigorous study of the Walras-Cassel equilibrium conditions was made by Wald[1951]. He proved that the existence and uniqueness of solution to the system. Dorfman, Samuelson and Solow[1958] provides a relatively transparent proof, which uses as tools the duality theorem of linear programming and the fixed-point theorem of Kakutani. The problem in its dual linear-programming forms, as presented by Dorfman, Samuelson and Solow[1958], is

(Primal) Maximize $\Sigma_j p_j b_j$ (≡value of output) subject to (3.1a) and $b_i \geq 0$.

(Dual) Minimize $\Sigma_i s_i q_i$ (≡total income) subject to (3.2a) and $q_i \geq 0$.

Instead of separately maximizing $\Sigma_j p_j b_j$ and minimizing $\Sigma_i s_i q_i$, we can maximize the difference between them or the total profit, $\Sigma_j p_j b_j$ - $\Sigma_i s_i q_i$. Duality theory tells us that the maximum value of toal profits achieved at a competitive equilibrium is zero. Elsewhere it is negative. It does not matter whether we think of profits being maximized in the aggregate or by individual competitive firms, all facing the same prices. Thus, the competitive equilibrium examined with total ouput and total income is identical with competitive equilibrium defined in terms of profit maximization. Therefore, the following problem possesses also a unique solution and the input-output pattern is efficient:

Maximize $\Sigma_j p_j b_j - \Sigma_i q_i s_i$

subject to (3.1a):

$$a_{11}b_1 + a_{12}b_2 + \dots\dots\dots\dots + a_{1n}b_n \leq s_1$$

$$a_{21}b_1 + a_{22}b_2 + \dots\dots\dots\dots + a_{2n}b_n \leq s_2$$

$$\dots\dots\dots\dots\dots\dots\dots\dots$$

$$a_{m1}b_1 + a_{m2}b_2 + \dots\dots\dots\dots + a_{mn}b_n \leq s_m$$

and the equilibrium factor prices will satisfy the dual inequalities (3.2a):

$$a_{11}q_1 + a_{21}q_2 + \ldots\ldots\ldots\ldots\ldots\ldots + a_{m1}q_m \geq p_1$$
$$a_{12}q_1 + a_{22}q_2 + \ldots\ldots\ldots\ldots\ldots\ldots + a_{m2}q_m \geq p_2$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$a_{1n}q_1 + a_{2n}q_2 + \ldots\ldots\ldots\ldots\ldots\ldots + a_{mn}q_m \geq p_n$$

B. GENERAL TRANSPORTATION PROBLEM

Some modifications would be needed before the formulation can be applied to model the oil and oil-tankers system. In reality, there is often a transportation cost c_{ij} involved in shipping a unit of ith resource to the site when the jth commodity is produced. Letting $x_{ij} = a_{ij}b_j \equiv$ the amount of ith resource shipped to produce jth commoditiy, we can tranform the equilibrium system to a generalized transportation model involving "price-sensitive" (i.e., price dependent) supply and demand functions (the interpretation of these price-sensitive functions, $f_i(s_i)$ and $f_j(b_j)$, is represented in the next section). Conditions (3.1a) would become $\Sigma_j x_{ij} \leq s_i$ ($\forall$ i) and "equating" shipments to demand at each demand destination j gives $\Sigma_i x_{ij} \geq b_j$ ($\forall$ j) or "shipments must not fall short of demand". The net profit would then need to be further reduced by the total shipping costs $\Sigma_{ij} c_{ij} x_{ij}$ and thus, the following transportation model results:

Maximize $\quad \Sigma_j f_j(b_j) - \Sigma_i f_i(s_i) - \Sigma_{ij} c_{ij} x_{ij}$

subject to :

$$\Sigma_j x_{ij} \leq s_i \qquad \forall\, i \qquad (3.3)$$
$$\Sigma_i x_{ij} \geq b_j \qquad \forall\, j \qquad (3.4)$$
$$x_{ij},\ s_i,\ b_j \geq 0 \qquad \forall\, i, j$$

(We will defer the discussion on equilibrium factor prices, the duals, at this point.)

As we shall see, the mathematical programming model to be used involves nonlinear programming rather than just linear programming. Equations (3.3) state that at each supply origin, the shipments from the origin could not exceed its local supply. Similarly, equations (3.4) state that at each demand destination, the shipments must suffice to cover the local demand. They are equivalent to the conditions of type (3.1a) or "demand $\leq$ supply". There will also be complementary conditions of type (3.2a) or "(price) x (supply-demand) = 0" typing the imputed price (the dual variable at the origin/demand destination) to the gap between the supply/demand

and total shipments. In the case where total demand is less than total supply, the market price of the commodity must be zero, and the commodity is a "free good", as pointed out by Zeuthen and Neisser (Dorfman, Samuelson and Solow [1958]).

C. CONSTANT FREIGHT RATE MODEL

To better relate the model to the oil issue, I have redefined the notation:

i = oil exporting regions, e.g., Middle East, $i = 1,..,m$.

j = oil importing regions, e.g., Japan, $j = 1,..,n$.

s_i = oil supply in region i.

b_j = oil demand in region j.

x_{ij} = the quantity of oil to be shipped from region i to region j.

$\gamma_i + \delta_i s_i$ = supply price (marginal cost) of oil at region i, where γ_i, δ_i are constants.

$\alpha_j - \beta_j b_j$ = market price of oil in region j, where α_j, β_j are constants.

d_{ij} = shipping distance between region i and region j.

f = marginal freight rate (marginal cost of shipping a unit of oil over one nautical mile).

c_{ij} = unit cost of shipping the oil from region i to region j = $f\, d_{ij}$.

The supply price of oil at region i is defined as the lowest price that the ith oil exporter requires in order to be willing to supply the quantity s_i of oil. In equations (3.1), the system assumed that the supply function was perfectly inelastic or vertical. To allow for the possibility that the exporter may be willing to respond to a higher price by supplying an increased quantity, the supply price can be expressed as $\gamma_i + \delta_i s_i$ with δ_i (> 0) (Thompson and Thore[1992], see Figure 3.1) reflecting the elasticity of supply at ith region. As the equilibrium solution will not permit the presence of any positive profits (beyond the payments to all productive factors), the supply price is therefore the same as the marginal cost of production. Therefore, the total costs of producing s_i unit of oil can be obtained by integrating the production marginal cost curve $\gamma_i + \delta_i s_i$:

$$f_i(s_i) = \int(\gamma_i + \delta_i s_i)ds_i = \gamma_i s_i + \tfrac{1}{2}\delta_i s_i^2 + \text{integration constant}$$

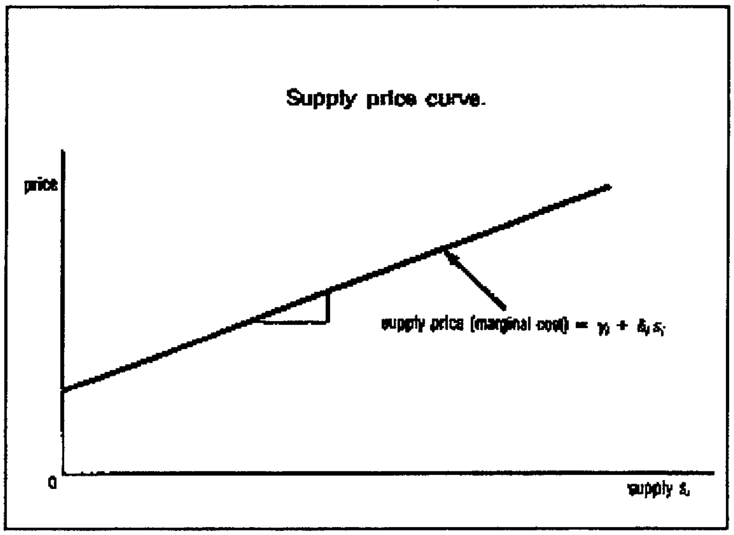

Figure 3.1 A typical supply price curve.

As for the case of the price-sensitive demand, the demand price in region j is defined as the highest price that the jth importer would be willing to pay to buy quantity b_j of oil. It can also be expressed as $\alpha_j - \beta_j b_j$ with β_j (> 0) reflecting the elasticity of demand at region j. Similarly, the total demand at region j is given by:

$$f_j(b_j) = \int \alpha_j - \beta_j b_j \, db_j = \alpha_j b_j - \tfrac{1}{2}\beta_j b_j^2 + \text{integration constant}$$

The objective function now becomes $\Sigma_j(\alpha_j b_j - \tfrac{1}{2}\beta_j b_j^2) - \Sigma_i(\gamma_i s_i + \tfrac{1}{2}\delta_i s_i^2) - \Sigma_{ij} f d_{ij} x_{ij}$ (constants ignored) and is known as an economic potential function. Note that the function is concave (it is a sum of linear functions and negative or inverted quadratic functions) and it has a maximum at the desired point solution. It has no direct economic interpretation and is used as a mathematical artifact only. The entire nonlinear program now reads:

Maximize $\Sigma_j(\alpha_j b_j - \tfrac{1}{2}\beta_j b_j^2) - \Sigma_i(\gamma_i s_i + \tfrac{1}{2}\delta_i s_i^2) - \Sigma_{ij} f d_{ij} x_{ij}$

subject to :

$$\Sigma_j x_{ij} \le s_i \qquad \forall\, i \tag{3.3}$$

$$\Sigma_i x_{ij} \ge b_j \qquad \forall\, j \tag{3.4}$$

$$x_{ij},\ s_i,\ b_j \ge 0 \qquad \forall\, i, j$$

The objective function is concave, and the constraints are linear, so that the program is actually an instance of quadratic programming. It has a unique optimal solution.

D. ECONOMIC INTERPRETATION OF THE MODEL

Let the Lagrange multipliers or the dual variables of the two sets of constraints (3.3) and (3.4) be μ_i and v_j, respectively. The multipliers μ_i are nonpositive and the multipliers v_j are nonnegative. Denoting the optimal solution by an asterisk (*), the multiplier μ_i^* may be interpreted as the negative of the imputed unit cost of one unit of oil available at the region i. It is the imputed equilibrium oil price or f.o.b. (free on board) oil price at exporting region i. The multiplier v_j^* may be interpreted as the equilibrium oil price in importing region j or the landed oil price. The Kuhn-Tucker conditions state:

$$\mu_i^* (\Sigma_j x_{ij}^* - s_i^*) = 0, \quad \forall\, i \tag{3.5}$$

$$v_j^* (\Sigma_i x_{ij}^* - b_j^*) = 0, \quad \forall\, j \tag{3.6}$$

$$\mu_i^* + v_j^* \leq fd_{ij}, \quad x_{ij}^*(fd_{ij} - \mu_i^* - v_j^*) = 0, \quad \forall\, i, j \tag{3.7}$$

$$-\mu_i^* \leq \gamma_i + \delta_i s_i^*, \quad s_i^*(\gamma_i + \delta_i s_i^* + \mu_i^*) = 0, \quad \forall\, i \tag{3.8}$$

$$v_j^* \geq \alpha_j - \beta_j b_j^*, \quad b_j^*(v_j^* - \alpha_j + \beta_j b_j^*) = 0, \quad \forall\, j \tag{3.9}$$

In words, conditions (3.5) state if the equilibrium f.o.b. price μ_i^* of the supply is nonzero, then the optimal shipments will exactly equal the supply. But if the shipments fall short of the available supply, μ_i^* must have haven to zero. Similarly, conditions (3.6) state that the equilibrium landed price v_j^* can only be positive if the shipments equal total demand. Conditions (3.7) state that the price appreciation $\mu_i^* + v_j^*$ must not fall short of the shipment cost fd_{ij} for shipment x_{ij}^* to occur. Otherwise, a hypothetical shipper would suffer a unit loss and no shipments would occur. This set of conditions is comparable to conditions (3.2a) of the classic economic equilibrium system. Conditions (3.8) spell out the association between the equilibrium f.o.b. price μ_i^* and the supply price $\gamma_i + \delta_i s_i^*$. Again, μ_i^* must not be less than the supply price $\gamma_i + \delta_i s_i^*$ for a positive amount of s_i^* to be exported. Conditions (3.9) reflect the requirement for the equilibrium landed price v_j^* to be lower than the market price $\alpha_j - \beta_j b_j^*$ for any purchase b_j^* to take place.

E. PRICE-SENSITIVE TANKER SUPPLY AND FINAL MODEL

The study has so far assumed an unlimited supply of shipping capacity at a constant freight rate f, i.e., $\Sigma_{ij}x_{ij}$ is not restricted. In real life, the oil-tanker shipping capacity is limited and is usually subject to some degree of elasticity because of the opportunity for transfer of shipping capacity between services (e.g., oil-tankers in grain trades). Factors such as service speed, off-hire and port turnaround also influence the shipping capacity in terms of ton-miles. A related issue is how the supply or offering of tanker shipping is related to freight rates.

There are essentially two types of ratemaking in shipping, namely conference ratemaking and tramp ratemaking. Conference ratemaking is provided by associations of shipping companies which have come together to form liner conferences. They provide regular services (and capacities) on defined routes at agreed and published rates. Frankel[1987] shows that for a conference to maximize its profit, it will introduce a value-based tariff which will be higher than its average marginal costs for the average cargo carried, and these marginal costs could be used as the lower bound for its tariffs. The marginal cost can thus be seen as the lowest price a conference requires in order to be willing to supply an additional unit of shipping capacity. Tramp shipping (for independently-owned vessels) is generally assumed to be a freely competitive market in which prices are determined by supply and demand. As it is not the main player in conference-dominated markets, one can expect tramp ratemaking be very close or competitive to conference ratemaking. In this study, we will use the marginal cost curve as a price function for the tanker freight rates. Devanney[1973] developed supply curves in ton-miles (see Figure 3.2) for tankers as a function of marginal costs in US$/dwt. These indicate that freight rates are quite important for the short-run (a period too short for significant changes in overall shipping capacity through newbuilding, etc.) supply of capacity in the tanker trade.

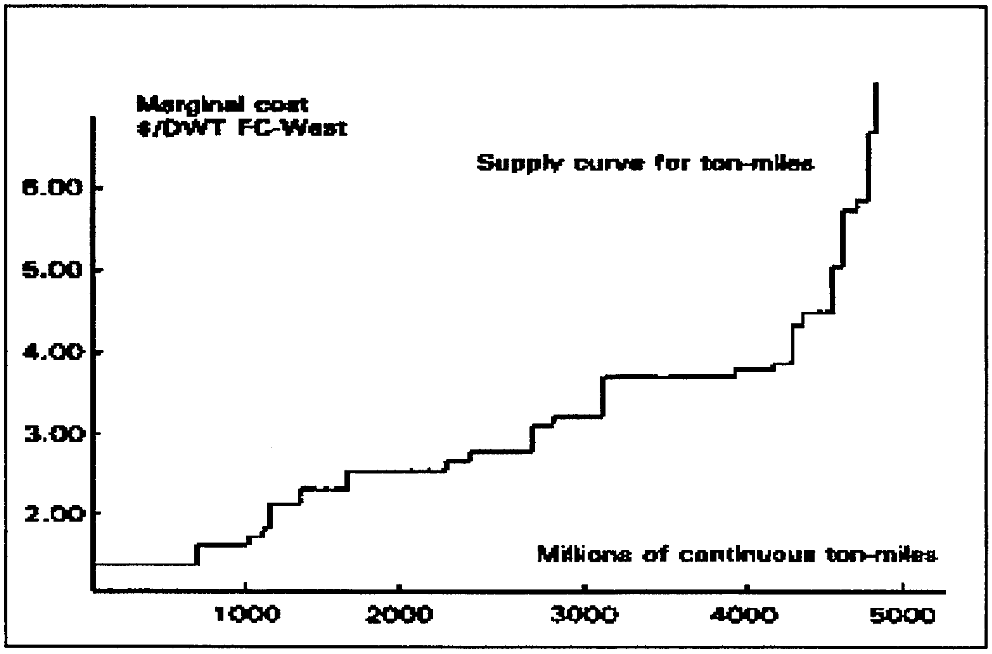

Figure 3.2 Supply curves in ton-miles for tankers as a function of marginal costs in US$/dwt.

After incorporating the price-sensitive tanker-supply, the model would become:

Maximize $\quad \Sigma_j(\alpha_j b_j - \frac{1}{2}\beta_j b_j^2) - \Sigma_i(\gamma_i s_i + \frac{1}{2}\delta_i s_i^2) - (\lambda t + \frac{1}{2}\omega t^2)$

subject to :

$$\Sigma_j x_{ij} \leq s_i \qquad \forall i \qquad (3.3)$$

$$\Sigma_i x_{ij} \geq b_j \qquad \forall j \qquad (3.4)$$

$$\Sigma_{ij} x_{ij} d_{ij} \leq t \qquad (3.10)$$

$$x_{ij}, s_i, b_j, t \geq 0 \qquad \forall i, j$$

where t represents the quantity of tanker capacity supplied and λ, ω (> 0) are constants. Like the price-sensitive supply functions, $\lambda + \omega t$ would be the supply price of the shipping capacity or the marginal shipping cost and $\lambda t + \frac{1}{2}\omega t^2$ ($\equiv \int(\lambda + \omega t)dt$, with the integration constant suppressed) gives the total shipping costs. Note that the concavity of the objective function is not affected by the new insertion.

Let the Lagrange multiplier of constraint (3.10) be τ (≤ 0) and τ^* can be interpreted as the imputed equilibrium freight rate of the system. The Kuhn-Tucker conditions related to τ are as follows:

$$\tau^*(\Sigma_{ij}x_{ij}^* - t^*) = 0 \tag{3.11}$$

$$-\tau^* \leq \lambda + \omega t^*, \quad t^*(\lambda + \omega t^* + \tau^*) = 0, \tag{3.12}$$

$$\mu_i^* + \nu_j^* \leq -\tau^* d_{ij}, \quad x_{ij}^*(-\tau^* d_{ij} - \mu_i^* - \nu_j^*) = 0, \quad \forall\, i, j \tag{3.7a}$$

Condition (3.11) states that if the optimum total shipments $\Sigma_{ij}x_{ij}^*$ fall short of the available tanker supply t^*, the equilibrium freight rate τ^* must have fallen to zero. If τ^* is nonzero in equilibrium, then those shipments must equal the tanker supply. Condition (3.12) reinstates the relationship between the equilibrium freight rate τ^* and the marginal shipping cost $\lambda + \omega t^*$. The equilibrium freight rate can never exceed the the marginal shipping cost or else no shipping capacity would be supplied. If a positive quantity of shipping capacity t^* is supplied, then the freight rate equals the marginal shipping cost. Conditions (3.7a) analogous to those in (3.7) can be interpreted as before with the exception that f is now replaced by $-\tau^*$.

IV. SCENARIO STUDY

This chaper presents the results of a scenario study on the significance of South East Asia's sealanes in the global seaborne oil trade. It uses the mathematical model derived in the previous chapter to illustrate what might happen in situations where these sealanes are no longer available to seaborne trade. The price-sensitive tanker supply function incorporated in the model would allow us to investigate both short-run (high supply inelasticity) and long-run (low supply inelasticity) effects in this study.

A. SCENARIO

To enter the Pacific Ocean from the Indian Ocean, one must either pass south and east of Australia or pass through one of the straits in the South East Asia region. The shortest of these routes is through the Straits of Malacca. It is also the only passage that is formally in international waters; all other passages go through Indonesian territory. Most oil shipments from the Middle East and Northern Europe to the major oil-consuming nations in the East Asia region pass through these sealanes. The oil shipments transiting this region account for about 15% of the world seaborne oil trade in terms of tons and about 20% in terms of tonne-miles. The alternate passage via Australia would nearly double the sailing distances from the Middle East to countries in North East Asia and thus, would very significantly increase the shipping demand in terms of tonne-miles. This study will examine how the oil trade and tanker market would react to such an extended trip, taking into consideration the supply and demand elasticities of oil in different regions.

This is a hypothetical study with 1982 data; I will not prophesy how such a scenario might arise. The year 1982 was characterized by depressed conditions similar to other years in the modern era. The international seaborne oil trade was decreasing and a large surplus overhanging the world tanker market was the result. The price-elasticities were assumed to be elastic at 0.67 across all supply regions and a unitary price-elasticity would be used for all oil demands (Kennedy, 1978). The average freight rate for 1982 was US$1.15 per barrel per 11,000 nm as reported in the Harvard Business School Report (Harvard, 1983). The f.o.b. oil prices and inter-

regional seaborne movements of crude oil were obtained from the U.S. Department of Energy (US DoE, 1995) and the Organization for Economic Cooperation and Development (OECD, 1983), respectively.

B. MODEL IN NPS FORMAT

* Indices:

i - (9) oil exporters:

USA, Canada, Latin America, Western Europe, North Africa, West Africa, Middle East, South East Asia and Eastern Europe.

j - (7) oil importers:

USA, Canada, Western Europe, Africa, South East Asia, Japan, Australia and Eastern Europe.

* Data:

es_i - price elasticity of supply curve i (=0.67).

eb_j - price elasticity of demand curve j (=1.0).

et - price elasticity of shipping supply curve (to be varied from 10 to 0.002).

$cs1_i$, $cs2_i$ - curve coefficients of supply curve i where:

$cs2_i$ = 1982 oil price (US DoE, 1995)/oil supplied by region i (OECD, 1983);

$cs1_i$ = 1982 oil price * (1 - 1/es_i)

($cs1_i$ derived from the supply equation: oil price = $cs1_i$ + $cs2_i$/es_i*supply).

$cb1_j$, $cb2_j$ - curve coefficients of demand curve j where:

$cb2_j$ = 1982 oil price (US DoE, 1995) / oil demand in region i (OECD, 1983);

$cb1_j$ = 1982 oil price * (1 + 1/es_i)

($cb1_j$ derived from the demand equation: oil price = $cb1_j$ - $cb2_j$/eb_j*demand).

ct1, ct2 - curve coefficients of shipping supply curve where:

ct1 = 1982 freight rate (Harvard, 1983) / shipping supply in 1982 (OECD, 1983);

ct2 = 1982 freight rate * (1 - 1/es_i)

(ct1 derived from the supply equation: freight rate = ct1 + ct2/et*supply).

d_{ij} - shipping distance from exporter i to importer j in nm (Lloyd, 1981).

* Variables:

s_i - amount of oil supplied by exporter i in tons.

b_j - amount of oil imported by importer i in tons.

t - amount of shipping capacity utilized in ton-miles.

x_{ij} - amount of oil shipped from exporter i to importer j at l type freight rate in tons.

* Formulation:

Maximize $\sum_j(cb1_j*d_j - \frac{1}{2}cb2_j*d_j^2/eb_j)$

$- \sum_i(cs1_i*s_i + \frac{1}{2}cs2_i*s_i^2/es_i)$

$- \quad (ct1*t + \frac{1}{2}ct2*t^2/et) \qquad = EP$ (economic potential)

subject to the constraints:

$$\sum_j x_{ij} \leq s_i \qquad \forall i$$

$$\sum_i x_{ij} \geq b_j \qquad \forall j$$

$$\sum_{ij} x_{ij} d_{ij} \leq t$$

$$s_i, b_j, x_{ij} \geq 0$$

The model is essentially the same as that shown in Chapter III with the following exceptions:

$cb1_j \equiv \alpha_j$, $cb2_j/eb_j \equiv \beta_j$,

$cs1_i \equiv \gamma_i$, $cs2_i/es_i \equiv \delta_i$,

$ct1 \equiv \lambda$, $ct2 \equiv \omega$.

(The model in GAMS codes is given in Appendix A.)

C. APPROACH

The approach was first to validate the model by comparing the simulated results with the actual outcomes in 1982. We then proceed to inject the scenario of "losing" the South East Asian sealanes at different shipping supply elasticities (et, in the model) and note how the equilibrium oil prices, distribution pattern and freight rate were affected. The unavailability of the sealanes or "crisis" was simulated by adjusting the affected distances between exporters and importers (d_{ij}'s, 7in the model).

D. RESULTS AND ANALYSIS

The model was able to produce oil productions and demands close to the actual outcomes in 1982 (Appendix B lists both the simulated and actual outcomes). Below are results associated with the denial of South East Asian sealanes to world seaborne oil trade.

1. Freight Rates

Figure 4.1 shows how the freight rate in crisis is expected to vary over the range of shipping inelasticities defined between 0.1 (very elastic) to 500 (very inelastic). The freight rate prior to the disruption was about 0.1 US$ per ton-mile and according to the plot, it is expected to raise rapidly with the elasticity of the shipping supply during the crisis.

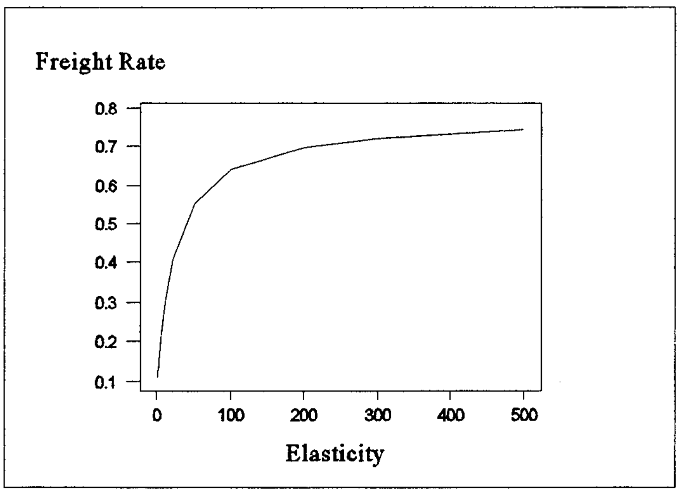

Figure 4.1 Freight Rate versus Shipping Supply Elasticity

Figure 4.1 also suggests that the rate of increase would slow down at some critical elasticity and level off at an equilibrium freight rate of about 0.75 US$/ton-mile or seven times the pre-disruption rate. This maximum value also serves as an upper bound for the freight rate in crisis -- the maximum freight rate one could expect in the absence of any prior knowledge about the shipping supply elasticity. Any higher freight rate would result in "unprofitable" oil trade and thus, would not happen (based on the set of oil demand and supply functions used in this study).

2. Shipping Demands

The unavailability of Sea East Asian sealanes can be viewed as an overall reduction in the transportation efficiency as tankers would now need to sail much longer distances for oil deliveries. The inefficiency translates to additional transportation costs and, thus, oil prices increase and overall oil consumption decreases. However, lower oil consumption does not necessarily lead to lower shipping demand which is often expressed in terms of laden ton-miles. Figure 4.2 shows how the shipping demand (in terms of laden ton-miles and expressed as a percentage increase in shipping demand from the pre-disruption level) would be affected by the elasticity of shipping supply in crisis.

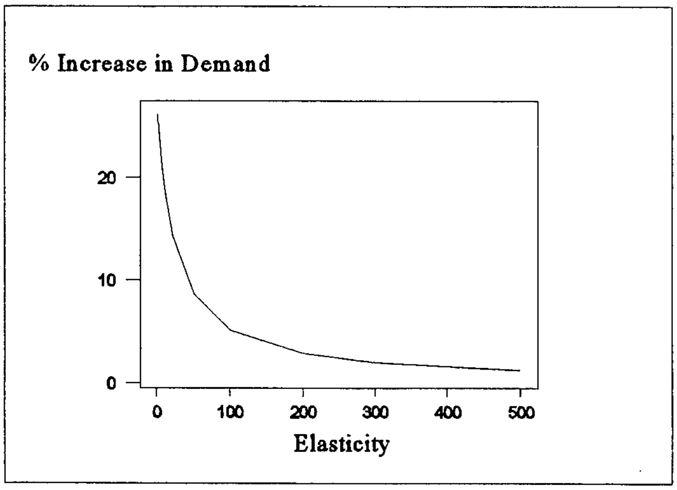

Figure 4.2 Percentage Increase in Shipping Demand versus Elasticity of Shipping Supply.

As expected, the shipping demands during crisis are generally higher (when compared to the pre-disruption level) as the average sailing distance is now higher. The increase in shipping demand could be as high as 27% in cases where the shipping supply is elastic. The increase in shipping demand falls with the increase in elasticity of shipping supply in crisis (a direct reversal of that of freight rates) and approaches zero when the elasticity is very high. High elasticity implies that it would be very expensive to step up the shipping supply; it would not be profitable for the nations to demand more shipping capacity and the final demand would stay close to the pre-disruption level. With elastic shipping supply, nations would take advantage of the low freight rate to sustain their respective oil consumption at the pre-disruption level.

3. Oil Prices and Oil Distribution Patterns

As mentioned in earlier discussion, the absence of South East Asian sealanes from the global seaborne oil trade could be translated to higher transportation costs. The results suggest that when the shipping supply is elastic, the equilibrium oil prices would not change much as the trade would continue to enjoy a low freight rate and transportation costs remain as a small portion of the overall oil prices. However, some changes to the oil distribution pattern are noted. Due to the dramatic increase in the sailing distance between Japan and its traditional oil source in the Middle East, Japan would now find it attractive to import oil from North America (USA and Canada) instead; a significant increase in oil trade between North America and Japan can be expected. Despite the increased oil trade between Japan and North America, the Middle East would continue to be the major oil source for Japan. It is also noted that the Middle East would export more oil to Western Europe and North America as a consequence of the changes in sailing distances. Table 4.1 summarizes the changes in oil distribution in situations where the shipping supply is elastic.

However, when the shipping supply is inelastic, the freight rate would soar as shown in Figure 4.1 and, coupled with the dramatic increasing in sailing distances between some regions, some significant changes in both f.o.b and landed oil prices could be expected in these regions. Key "losers" in this scenario are the Middle East and Japan where the Middle East can expect its oil production to be reduced by about 24% (and a 15% cut to its oil price) and the landed oil price in Japan is expected to soar by about 11%. The Middle East is expected to absorb much of the increase in transportation cost to Japan (because of the increased sailing distance) in order to compete with other exporters. Part of the increase in transportation cost would be absorbed by Japan itself and thus, a rise in Japanese oil prices occur. The Western European importers can also expect a price rise of about 8% as a result of the reduction in the Middle East's oil production. The "big winners" in this case would be Latin America's oil exporters as they could now demand higher prices for their oils because of their proximity to Japan. The traditional importers of Latin America's oils, the USA, would be victimized by these changes, seeing its landed oil price soar by about 8%. No significant increase in oil trade between Japan and Latin America is noted as a result of the increased export from Latin America to the USA and the Middle East exporters'

willingness to reduce their prices. Other changes may be considered as relatively insignificant. The summary is shown in Table 4.2 and Table 4.3.

From	To	Pre-Crisis Flow (in million tons)	Post-Crisis Flow (in million tons)
United States	Western Europe	10.53	0
Canada	Western Europe	9.43	0
United States	Japan	0.00	10.32
Canada	Japan	0.00	9.17
Western Europe	United States	8.50	7.43
Western Europe	Canada	18.13	18.41
Latin America	United States	144.34	140.82
North Africa	Western Europe	82.32	79.67
West AFrica	Western Europe	61.00	58.93
Middle East	United States	0.00	34.38
Middle East	Western Europe	175.65	209.57
Middle East	Africa	24.04	24.52
Middle East	Japan	174.33	171.57
Middle East	Australia	10.58	10.78
Eastern Europe	Western Europe	60.40	58.53

Table 4.1 Changes in oil distribution pattern, elastic tanker supply (elasticity = 0.33).

Region	% Change in Oil Price	% Change in Oil Imported
United States	8.13	-7.47
Canada	4.98	-4.53
Western Europe	6.15	-5.65
Africa	-9.45	8.23
Japan	11.06	-9.88
Australia	-2.88	2.57

Table 4.2 Changes in oil importing regions (elasticity = 500).

Region	% Change in Oil Price	% Change in Oil Exported
United States	1.19	1.84
Canada	1.18	2.70
Latin America	6.28	8.88
Western Europe	-2.39	-3.71
Northen Africa	2.80	4.35
Western AFrica	-0.97	-1.55
Middle East	-15.18	-23.86
Eastern Europe	3.55	5.32

Table 4.3 Changes in oil exporting regions (elasticity = 500).

V. CONCLUSIONS

In Chapter I, we highlighted the importance and vulnerability of today's seaborne oil trade and explained how disruptions to tanker shipping can be represented. Chapter II analyzed the factors that influence freight rates using traditional static economic analysis. The analysis suggested that the Suez Canal had lost its profound influence on freight rates since its reopening in 1975. This is due to the development of supertankers such as the VLCCs and ULCCs, resulting in a highly competitive Cape of Good Hope route. It was also shown that freight rates are closely linked to tanker activities such as lay-up, delivery and utilization as one would expect. Chapter III was devoted to a theoretical discussion on how the classic economic equilibrium theory and nonlinear programming could be used to model a dynamic seaborne oil trade. It provides analysts with a way to factor in the price-sensitive demand and supply of oil and tankers which is not possible with the traditional static statistical approach. Chapter IV used the dynamic model to examine the importance of South East Asia's sealanes in the global seaborne oil trade. The results suggested that major oil importing nations such as Japan, the United States and Western European nations, as well as the biggest oil supplier of Japan, the Middle East, should not underrate the importance of these sealanes. In situations where the shipping supply is highly inelastic, which is often the case in the short-run, the closure of South East Asia's sealanes would place an enormous pressure on the world's fleets and cause freight rates to soar. These sealanes are more than virtual lifelines to South East Asian nations and Japan; many other nations, both oil importers and oil exporters, would also find themselves subsidizing the high freight rates should the incident arise. The development of supertankers has relieved the dependence of the West on the Suez Canal, but it has also created a highly inflexible and vulnerable shipping system. For those nations whose economies depend on oceanborne supply lanes, it is imperative to secure and protect South East Asia's sealanes.

APPENDIX A - GAMS PROGRAM

SETS

R regions

/USA,CAN,WEUR,AFRICA,SEA,JAP,AUS,LATIN,NA,WA,ME,EEUR/

I(R) oil exporters

/USA,CAN,LATIN,WEUR,NA,WA,ME,SEA,EEUR/

J(R) oil importers

/USA,CAN,WEUR,AFRICA,SEA,JAP,AUS/

C coefficients

/C1,C2/;

TABLE D1(I,J) one-way shipping distance between i and j in thousand miles

	USA	CAN	WEUR	AFRICA	SEA	JAP	AUS
USA	99999	99999	5.600	7.500	6.900	4.600	7.000
CAN	99999	99999	3.300	8.000	6.500	4.000	10.00
LATIN	1.000	3.200	4.700	4.700	9.000	8.000	8.000
WEUR	5.600	3.900	99999	3.000	12.70	14.50	12.50
NA	4.200	5.000	1.800	1.300	7.500	10.00	9.000
WA	5.200	5.000	3.800	4.600	9.000	10.90	8.500
ME	12.00	12.60	11.10	2.900	3.800	6.700	6.300
SEA	7.000	7.900	12.70	4.600	99999	2.600	2.500
EEUR	5.900	4.200	1.400	3.300	13.00	14.80	12.80

;

TABLE D2(I,J) one-way shipping distance between i and j in thousand miles *without "SEA"*

	USA	CAN	WEUR	AFRICA	SEA	JAP	AUS
USA	99999	99999	5.600	7.500	99999	4.600	7.000
CAN	99999	99999	3.300	8.000	99999	4.000	10.00
LATIN	1.000	3.200	4.700	4.700	99999	8.000	8.000
WEUR	5.600	3.900	99999	3.000	99999	16.55	12.50
NA	4.200	5.000	1.800	1.300	99999	16.55	9.000
WA	5.200	5.000	3.800	4.600	99999	14.00	8.500
ME	12.00	12.60	11.10	2.900	99999	12.60	6.300
SEA	99999	99999	99999	99999	99999	99999	99999
EEUR	5.900	4.200	1.400	3.300	99999	16.85	12.80

;

PARAMETER D(I,J);

D(I,J) = D1(I,J) (comment: or D2(I,J));

PARAMETER ES(I) supply elasticity in region i /

USA 0.67, CAN 0.67, WEUR 0.67, SEA 0.67

LATIN 0.67, NA 0.67, WA 0.67, ME 0.67, EEUR 0.67/;

PARAMETER EB(J) demand elasticity in region j/

USA 1, CAN 1, WEUR 1, AFRICA 1, SEA 1, JAP 1, AUS 1/;

PARAMETER tanker supply elasticity ET /1/;

TABLE CS(C,I) supply curve coefficients of exporter i

	USA	CAN	WEUR	SEA	LATIN	NA	WA	ME	EEUR
C1	-116.9	-117.3	-116.97	-122.9	-98.3	-119.7	-123	-118.1	-111.9
C2	19.98	22.55	7.90	4.646	1.62	2.575	3.38	0.434	3.644

;

TABLE CB(C,J) demand curve coefficients of importer j

	USA	CAN	WEUR	AFRICA	SEA	JAP	AUS
C1	464.41	464.41	464.41	464.41	464.41	464.41	464.41
C2	-1.346	-13.42	-0.6063	-10.32	-2.947	-1.284	-23.22

```
;
PARAMETER CT(C ) tanker supply curve cofficients /C1   0,   C2 0.00016/;
VARIABLES
   S(I)        oil supplied by importer i in million tons
   B(J)        oil imported by exporter j in million tons
   T           tanker capacity supplied in trillion ton-miles
   X(I,J)      oil shipped from i to j in million tons
   EP          economic potential;
POSITIVE VARIABLES S, B, X, T;
EQUATIONS
   OBJ         economic potential
   BES(I)      supply balance equation in region i
   BEB(J)      demand balance equation in region j
   BET         tanker supply balance equation;
OBJ..       -SUM(I,CS("C1",I)*S(I)+CS("C2",I)*S(I)**2/2/ES(I))
                  + SUM(J,CB("C1",J)*B(J)+CB("C2",J)*B(J)**2/2/EB(J))
            - SUM(L,CT("C1")*T+CT("C2")*T**2/2/ET)          =E=   EP;
BES(I)..    SUM(J,X(I,J)$(D(I,J) < 9999))                   =L=    S(I);
BEB(J)..    SUM(I,X(I,J)$(D(I,J) < 9999))                   =G=   B(J);
BET..       SUM((I,J),X(I,J)*D(I,J))                        =L=   T;

MODEL TANKER /ALL/;
SOLVE TANKER USING NLP MAXIMIZING EP;
```

APPENDIX B - SIMULATED AND ACTUAL OUTCOMES

Oil Importing Region	Actual Amount Imported (in million tons)	Simulated Amount Imported (in million tons)
United States	172.5	179.86
Canada	17.3	18.13
Western Europe	383.0	399.34
Africa	22.5	24.04
South East Asia	78.8	83.975
Japan	180.8	191.02
Australia	10.0	10.58

Table B1 Simulated demands in oil importing regions.

Oil Exporting Region	Actual Amount Exported (in million tons)	Simulated Amount Exported (in million tons)
United States	11.7	10.54
Canada	10.4	9.43
Latin America	121.3	144.34
Western Europe	29.6	26.63
South East Asia	52.9	43.71
Northen Africa	93.0	82.32
Western Africa	72.7	61.0
Middle East	544.0	468.57
Eastern Europe	61.4	60.40

Table B2 Simulated productions in oil exporting regions.

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5. Professor Gregory Hildebrandt, SM/Hi 4
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   Naval Postgraduate School
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